

HIGH SPEED INTEGRATED SIGNALING SYSTEM FOR UNDERGROUND MINES

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ABSTRACT

All most every underground mine is exposed to a number of risks - exposure to fire, roof falls or explosions tearing down wires, power failure or battery failure. So, underground mines mainly rely on alarm systems, such as stench gas, audible or visual alarms, pager phones, telephones, and messengers to warn miners of fire or other emergencies. These systems are often slow, unreliable, and limited in mine coverage. Meanwhile, many well-known research and commercial institutes have established many communication signaling systems: Through-the-Wire (TTW), Through-the-Earth (TTE), and Through-the-Air (TTE) etc. Coal mines are particularly unique environment for radio signals. Stopping or roof falls halt or impede conventional radio signal propagation. It is also believed that ionized air resulting from a mine fire could be a problem. In this paper we have developed a simple, cost effective, high speed integrated circuit designing to cope with the failing of alarming systems inside the mine. Single receiver may not be sufficient, as signal may be lost in between. So, we monitored signals, received by different receivers, situated at different places, inside the mine to ensure more safety. This system includes the application of high speed data acquisition, processing and decision making circuits.

Keywords —Analog to Digital Converter (ADC), Field Programming Gate Array (FPGA), Digital Storage Oscilloscope (DSO), Fast Fourier Transforms (FFT), Tri-Mode Ethernet Media Access Controller (TEMAC), Serial Port Interface (SPI)

I INTRODUCTION

Mine Safety and Health Administration (MSHA) statistics indicates that 107 underground fires occurred in coal and metal/nonmetal mines from 1990 to 1995 in the United States. Survival for underground miners during a fire or other emergency can be measured in terms of minutes. An emergency warning that arrives late can result in tragedy. Existing warning systems for underground mines, such as horns, sirens, stench gases through the ventilation system, or messengers, can be slow and ineffective. This promoted the development of an effective, fast acquisition and processing system for radio signaling system.

In addition to the fast acquisition, single receiver acquisition may not work properly, because the signal coming from any transmitter may be lost or distorted before reaching to the receiver. So we placed multiple receiver block, connected to the signaling system, at different direction and places. The received signals, from every receiver are fed to the signaling system for further processing. To established communication inside the mine frequency should be low enough to penetrate the rocks inside the mine. Radio frequency is a rate of oscillation in the range 3 KHz to 300 GHz. So we have designed the signaling system for. This mid frequency back-end of the signaling and communication system has three modules (see Fig.1). These modules are: 1. Data Acquisition Module, 2. Data Processing Module, 3. Decision Making and Re-transmission Module.

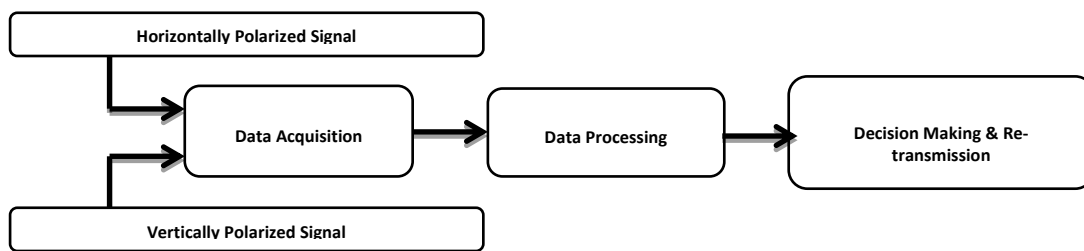


Fig 1: Block Diagram of the Different Modules of the Signaling System

1.1 Data Acquisition Module

In the Data Acquisition Module, for the front-end part, we have placed multiple identical receiver modules at different places inside the mine. After the signals, received by receivers, placed at different places, are fed to the back-end digital integrated module. Here the signal, used is circularly polarized, to reduce signal fading at the receiver. So, the receiver sends, horizontally and vertically polarized signal to the Dual Channel, high speed, 8 bit Analog to digital converters (ADC) to convert them to digital signals. Here, the analog signals are sampled according to the Nyquist's criterion. Here we have tested out circuit using two polarized signal from single receiver only. These ADCs are programmed by a Spartan-6 FPGA (Field Programming Gate Array). After the digitization of the signals, data from the ADCs is fed to the FPGA, through parallel bus. Here the FPGA is having higher operation speed, so that, the ADC buffers do not saturate. In the FPGA each byte of the received data is packetized according to the TCP/IP header format. After attaching the header to the data byte the packet is fed to the processing computer via Tri-mode Ethernet communication. Tri-mode Ethernet communication is having three mode of transmission i.e. 10 Mbps, 100 Mbps and 1 Gbps. For our system we fixed this communication for the 1 Gbps only. For 1 Gbps Ethernet communication (see Fig.2) we have used Xilinx TEMAC core which have TCP/IP protocol inside. The packets from the FPGA are sent to the Ethernet PHY Chip, which sends the packets serially to the Ethernet port of the computer through RJ_45 cables. This Ethernet Mac communication is a full-duplex communication. A SPI boot flash is connected to the FPGA to program the FPGA whenever it boots, so that we do not have to program FPGA every time.

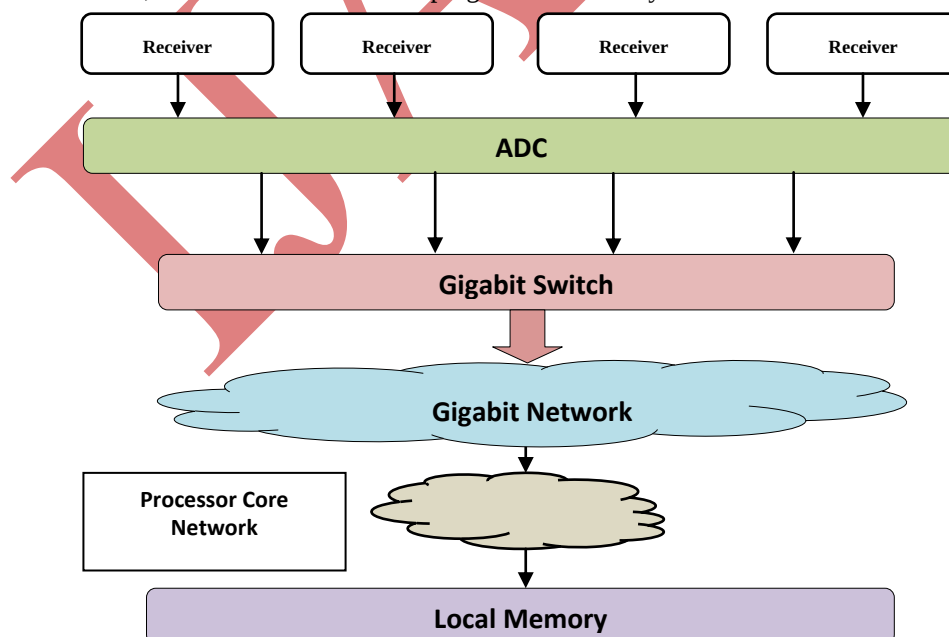


Fig 2: Schematic Depicting the Various Network of the Signaling System

1.2 Data Processing Module

Data, available at the computer port is dumped inside the computer hard disk, using the Socket programming for further processing. Here horizontally and vertically polarized signal data from the receiver is dumped inside the two binary files, inside the hard disk. This software Data Processing Module (see Fig: 3) is having different part. These parts are 1. Correlation, 2. Correlated Power Measurement, 3. Comparator.

1.3 Correlation

As we have taken data from single antennas for testing, the horizontally and vertically polarized binary data files are correlated to get the correlated data. The correlation is done in frequency domain. To convert the data to frequency domain, we have taken 1024 point FFT. After the FFT, the two dataset are correlated in frequency domain. Correlation in frequency domain can be related as.

$$\text{Corr}(g, h) \rightarrow G(f).H^*(f)$$

Where $g(t)$ and $h(t)$ are two functions in time domain and $G(f)$ and $H(f)$ are respective functions in frequency domain

1.4 Correlated Power Measurement

After the correlation, the maximum correlated power is measured in dB. The correlated power can be described in the following way.

$$G_{xy}(f) = \lim_{T \rightarrow \infty} \frac{X_T(f)Y_T^*(f)}{T}$$

Where $x(t)$ and $y(t)$ are two signals in time domain.

1.5 Comparator

After, the calculation of the correlated power, the correlated power is compared with the threshold level. The threshold can be set only doing experiment inside the mines. This threshold values can vary depending upon the environment inside the mine. For different mines the Threshold value may change. In our case, we took 12 dB as Threshold.

If the correlated power is greater than the signal; value then the processor sends a flag byte, back to the FPGA, via Ethernet Mac through the RJ_45 cable connected. Otherwise the processor goes to idle mode. If the correlated powers from different receiver are above the threshold value, the processor takes the greatest value. This value ensures, which part of the mine is sending the signal.

1.6 Decision Making Module:

The FPGA receives the flag byte. After reading the flag byte the FPGA, makes Alarm and Re- Transmission output lines connected to the FPGA, high (see Fig.4). With this Alarm signal, being high the alarm starts ringing. The Re-Transmission signal, switches the Transmitter on to retransmit the same identical signal for the other part of the mine, where the original signal may not reach. This Re-transmission includes the entire signal to reach most of the part of the mine to ensure the safety. For multiple receiver application, if the signal strengths, received, are above the threshold for all the receivers, the processors choose the maximum value available. This maximum value show, which direction the signal is coming in and the minimum value shows in which direction the signal is weak. So, signal can be retransmitted to that direction so that the disaster signal can reach most of the part inside the mine. The individual signaling module can be placed in the different parts of the mine to ensure coverage to most of the part of the mine (see Fig. 5).

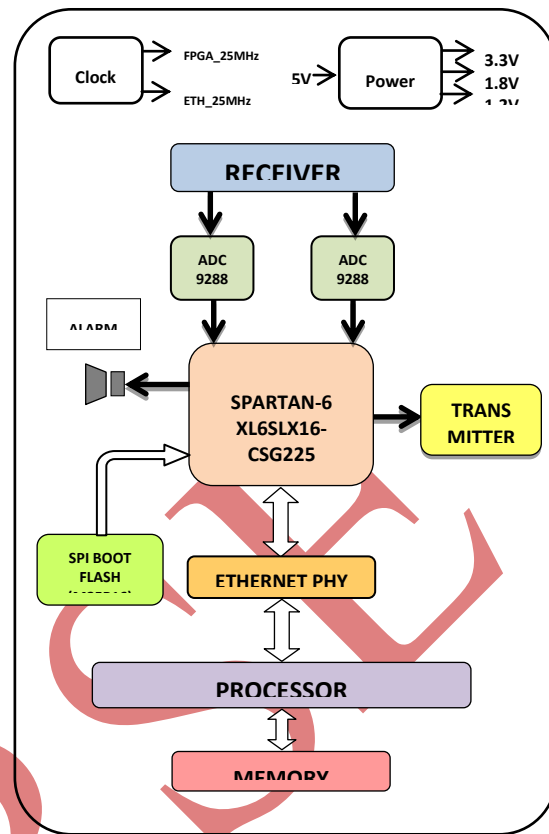
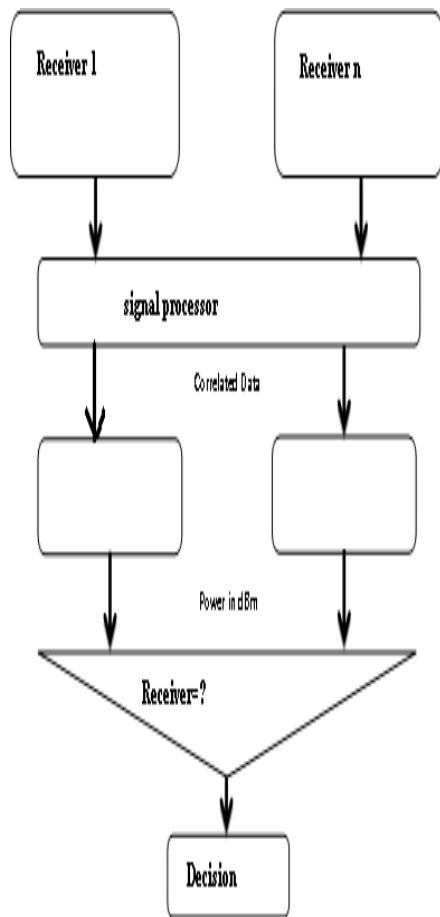


Fig.3: Block Diagram of the Software Data Processing Module **Fig.4: Block diagram of the card of the signaling system**

This signaling system can also be used for voice communication also. Data, received, can be stored and analyzed to study the effect of change in environment on communication signals. This will lead to the system modification and further processing.

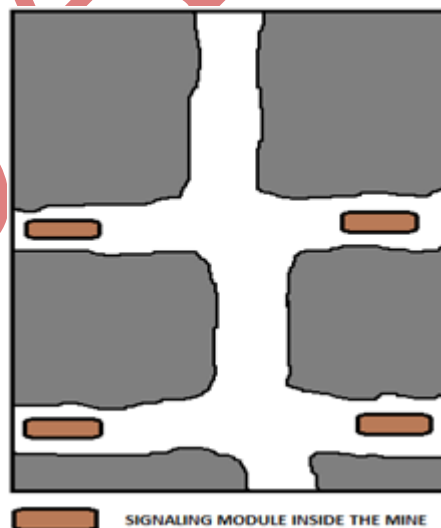


Fig 5: Signaling Modules inside the Mine

II. TESTING

We have tested our circuits for the single receiver only. Transmitter and receiver line-of-site and out-of-line-of-site have also been taken into consideration.

2.1 Components used

AD9288 (dual channel, 8 bits, high speed ADC), Spartan-6 FPGA (XL6SL16-CSG225), SPI Boot Flash (M25P16), Ethernet-PHY, RJ_45 Cables, SMA connectors. Coaxial cables, Intel Core i3 Processor, 2nd Generation.

2.2 Apparatus used

DSO, DSO Probes, Multimeter.

2.3 Simulation Softwares

Xilinx ISE-12.3, GCC Compiler, Gnuplot.

III. RESULTS

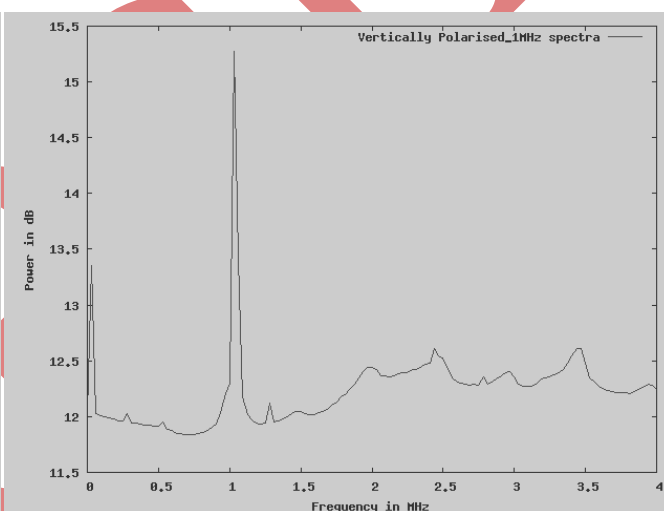
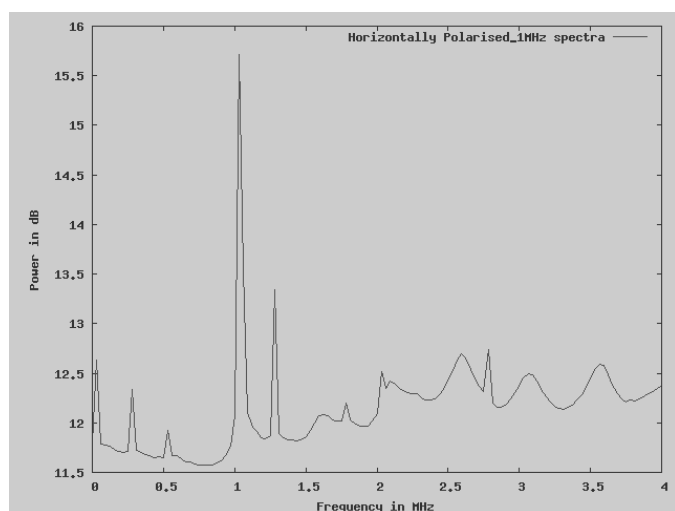


Fig 6: Cumulative Spectrum of 1MHz Horizontally Polarized Signal Fig 7: Cumulative Spectrum of 1MHz Vertically Polarized Signal

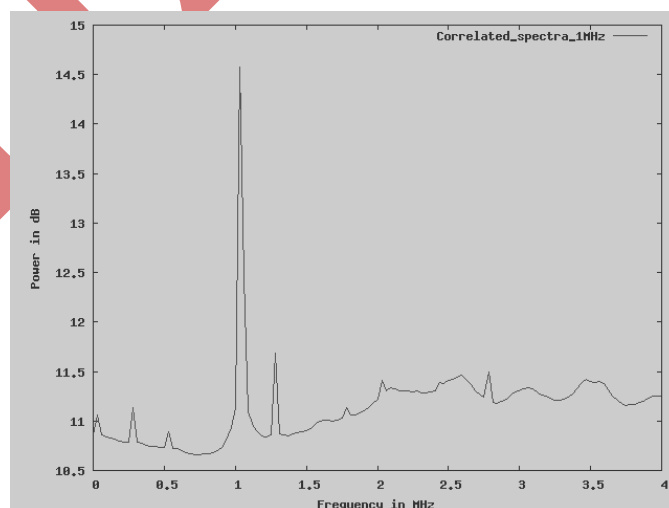


Fig: 8: Correlated Spectrum of 1MHz Circularly Polarized Signal

The Power of the Horizontally Polarized signal, Vertically Polarized Signal and Correlated Signal, measured are respectively 15.75 dB, 15.3 dB and 14.6 dB.

IV. APPLICATION

This high speed integrated signaling system can benefit the communication and signaling inside the mines. It would also be helpful to decrease the possibility of accidents inside the mine. As the data acquisition and processing, both are high speed, so the detection of the disaster signal will be very quick and accurate. In addition to this, this signaling system can trace, at which direction the disaster signal is coming from. The Re-transmission module re-transmits that signal to the other part of the mine. Moreover, the acquired data can be stored and analyzed later to trace the changes of the signal with the change of the environment in the mine. This system can also be used for military application also.

V. CONCLUSION

A disaster-warning alarm system has been developed, which functions receiving and Re-transmitting an RF signal all over the mine to underground working where miners equipped with personal pagers can receive the disaster signal. The loss and the fading of the signal were the main drawback for signaling inside the mine. So, we introduced a signaling system. Where we have monitored signals coming from identical receivers, placed at different places inside the mine to make the signaling system more sensitive to the upcoming signals.

As, this system receives signals from multiple receivers, it is capable of tracing the direction of the signal, coming in analyzing the signal power from different receivers. The re-transmission block re-transmits the identical signal to the rest of the mine again to maintain the signal power level inside the mine, so that the communication exists properly inside the mine. The repetition of this module inside the mine as a module can solve the communication problem, discussed above.

The acquired data can be stored to analyze the change the signal property with the change of the gas density, temperature, fire etc. This analysis would be helpful to reduces under-mine accidents.

Though the system, described in this paper may seem expensive but the reason for opting digital data acquisition and processing system is that, this system can be widely used for voice communication, signal property analysis and signal processing inside the mine rather than transmitting single frequency signaling and alarm system.

Moreover the basic idea has been implemented as the signaling system is giving satisfactory during the testing. We have tested with a single receiver and the data acquisition and processing systems are responding very well. Selection of Medium frequency for testing ensures the capability for low frequency application also.

In future we have thought of introducing high speed AURORA links, enormous usage of signal processing and noise cancellation locks and repeaters to test real scenarios inside the mines.

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